N.A.A.S. QUARTERLY REVIEW

No. 49 · *Autumn* 1960

MINISTRY OF AGRICULTURE, FISHERIES & FOOD

LONDON: HER MAJESTY'S STATIONERY OFFICE

TWO SHILLINGS NET

N.A.A.S.

Quarterly Review

THE JOURNAL OF THE NATIONAL AGRICULTURAL ADVISORY SERVICE

VOL. XII AUTUMN 1960 NO. 49

LONDON: HER MAJESTY'S STATIONERY OFFICE

SINGLE COPIES: 2*s*. (*2s. 4d. by post*)

ANNUAL SUBSCRIPTION: 9*s*. 4*d*. (*including postage*)

SALES INQUIRIES should be addressed to the publishers at any of the addresses below.

EDITORIAL COMMUNICATIONS should be sent to the Editor, N.A.A.S. Quarterly Review, Ministry of Agriculture, Fisheries and Food, Room 284, Great Westminster House, Horseferry Road, London, S.W.1.

In the interests of factual reporting, occasional reference in this Review to trade names and proprietary products may be inevitable. No endorsement of named products is intended nor is any criticism implied of similar products which are not mentioned.

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London, W.C.2 423 Oxford Street, London, W.1
13a Castle Street, Edinburgh 2 109 St Mary Street, Cardiff
39 King Street, Manchester 2 Tower Lane, Bristol, 1
2 Edmund Street, Birmingham 3 80 Chichester Street, Belfast 1
or from any bookseller

Printed in England by Wm. Clowes & Sons Ltd

FARM MANAGEMENT

A Note by Arthur Jones, Chief Farm Management Adviser

During the last ten years or so great strides have been made in the development and application of the management or economic approach to farm advisory work. Indeed, this is a continuing process leading to improvements and refinements in the techniques and methods used. But the need to diagnose weaknesses in the farm business on the basis of an analysis of its existing performance and using the budgeting technique in considering the results of changes that are possible, remain basic requirements.

The following article describes a development which will be of interest to Advisory Officers. It is based on the concept of gross profits. Work in this field was developed in Northern Ireland by Mr. V. Liversage and it has been introduced in the Yorks. and Lancs. Region by Mr. G. B. Clarke, the Farm Management Liaison Officer. The implications and the general applicability of this method are at present being examined by a Working Party of Advisory Officers and Agricultural Economists who will be reporting on this matter to Regional Directors later this year.

New Tools in Farm Management

G. B. CLARKE

Farm Management Liaison Officer, University of Leeds

J. WHITE

National Agricultural Advisory Service, Beverley, Yorkshire

TECHNIQUES of analysing and comparing farm accounts and records to reveal business weaknesses or improvement possibilities are now quite familiar to N.A.A.S. officers. The technique of budgeting to test the financial effect of possible changes in farm production is also in common use by District Advisory Officers. What is now being attempted is the development of a technique which will show what should be budgeted, and which will by simple stages, lead to logical conclusions on just what is the best production plan for any particular farm.

First of all, it is useful to be familiar with one of the earliest economic concepts which distinguishes four types of resources or "factors of production": *land, labour, capital and managerial ability*. Three of these, land, labour and capital can be measured. Land in acres, labour in hours, days or years; capital in *£ s. d.* All farmers will have some measurable quantity of these three factors available for use in their business and the Farm Management problem in its simplest form is thus to answer three quesions: (1) what enterprises? (2) how large? (3) what methods? to adopt to get the best return from the available land, labour and capital.

The definition of "best return" in this context is that which will give the highest long-term cash margin over total costs.

Fixed and Variable Costs

If costs are examined more closely, two categories can be distinguished. Firstly come the general "overheads", e.g., regular labour, rent or mortgage payments, repairs and depreciation charges on buildings and machinery. These overheads are unlikely to be altered whatever enterprises are adopted for the farm, so they are often termed "*fixed costs*". Secondly, there are costs which are directly influenced by the acreage of the crop or number of livestock, e.g., seed, feed, fertilizer, casual labour and machinery running costs. These can be regarded as "*variable costs*".

Surplus income over and above variable costs is in the nature of a *gross profit* from which fixed costs have to be met. The remainder is then the margin over total costs which farm management seeks to keep at a high long-term level. Clearly, if fixed costs remain constant, then the greater the gross profit which the available resources can achieve, the greater will be the margin over total costs.

Programme planning is concerned with establishing the income and the variable costs for possible enterprises on a particular farm, and then in the light of this information selecting those enterprises and deciding their size to give the highest long-term gross profit.

Of course the ability to earn gross profit will eventually be halted when one of the available resources of land, labour or capital is exhausted. If it is known which of these resources is the most limiting, then the choice of enterprises can be made to yield the greatest gross profit per unit of that resource—acre of land, day of labour or £1 of capital. Programme planning can thus quite logically indicate different combinations of enterprises to suit the amounts of the various farm resources which are available. Farm analysis and appraisal can furnish much of the data needed, while in carrying out programme planning a ready-made budget automatically emerges.

Before pursuing further the interesting possibilities of programme planning, it is probably better to go back and consider more closely a very simple outline of what is involved in the technique.

Necessary Assessments

First of all, a sound technical appraisal of the farm and an understanding of what is permissible within the bounds of good husbandry are essential. A valid assessment of that elusive quality—the fourth factor of production "managerial ability"—is also necessary, together with an appreciation of the farmer's particular skills, likes and dislikes. These are vital in all farm advisory work and are equally required for programme planning.

Next comes the need for knowledge and judgment in listing the possible enterprises for the farm and the levels of yield and variable costs for each, which are considered appropriate for forward budgeting. These levels should not be those of the past if advice can improve them, but equally they should not be standards or pious aspirations

without reference to what is actually being achieved on the farm. Programme planning as an advisory tool should and readily can be adjusted to fit the individual farm.

Any limits to the sizes of the enterprises in the list of possibles should be noted—for instance a good husbandry limit to the acreage of potatoes or a buildings restriction on the number of cows. Merely listing such restrictions need not of course override common sense in subsequently considering the implications of removing the restriction.

Example*

1. *Land*—72 acres medium/light soil
2. *Labour*—Farmer, 1 man, 1 boy } Totalling approx. 620 hours per month
3. *Possible Enterprises*

	Limit
(a) Crops	
Potatoes	10 acres
Sugar Beet	10 acres
Wheat	—
Barley	—
Oats	—
(b) Stock	
Cows	20 head
Beef	30 head
Sheep	—
Pigs	200 baconers
Poultry	500 layers

4. *Enterprises in order of Gross Profit per Acre* (see tables in Appendix I and II)

	£	s.
Potatoes	70	4
Sugar Beet	40	18
Cows	37	12
Sheep	27	0
Wheat	25	16
Barley	25	7
Oats	24	10
Beef	19	10

* In this simplified example, only two factors of production will be considered—land and labour. Adequate capital will be assumed, as will the reliability of the assessment of managerial ability reflected in the levels of yield and variable costs. A single method of production will be considered for each enterprise. Gross profits are calculated on an annual basis.

Pigs and poultry have not been ranked in the list (Item 4) of gross profits per acre since they can be managed with virtually no land and are regarded in this example as eligible only to provide profitable employment for any spare labour after putting the land to its most rewarding use.

Choice of Enterprise

Having now established what resources are available, what enterprises are possible and the margin over variable costs (gross profit) which each

is expected to yield, certain questions can be posed and answered concerning a rational choice of enterprises. Assuming for the moment that enough labour is available to handle any technically acceptable combination of the possible enterprises, then the answer to the question of the order in which possible enterprises should be selected would be given in Item 4 in the list on page 3, i.e., potatoes first with a gross profit per acre of £70 4*s*. and beef last with a gross profit per acre of £19 10*s*.

Selection 1—as many acres of potatoes as possible. In this case 10 acres. The programme so far planned would be:

Crop	*Acres*	*Gross Profit* £
Potatoes	10	702

Selection 2—as many acres of sugar beet as possible. In this case 10 acres. The programme so far planned would then be:

Crop	*Acres*	*Gross Profit* £
Potatoes	10	702
Sugar Beet	10	409
	20	1,111

Selection 3—as many cows as possible. In this case (20 × 1·8) = 36 acres can be devoted to cows. The programme then becomes:

Crop	*Acres*	*Gross Profit* £
Potatoes	10	702
Sugar Beet	10	409
Cows (20)	36	1,353
	56	2,464

Selection 4—as many sheep as possible. In this case only 16 acres of land are left so the final programme becomes:

Crop	*Acres*	*Gross Profit* £
Potatoes	10	702
Sugar Beet	10	409
Cows (20)	36	1,353
Sheep (64)	16	432
	72	2,896

If all the judgments about this farm were correct and had been fully stated, the programme under Selection 4 would be the most profitable. Reconsideration of these judgments, whether of yields, variable costs, gross profits, possible enterprises and their limits or even of the amounts of the fixed factors, is not only possible at every stage but is directly encouraged by spotlighting important factors to consider.

At *Selection* 2 (if not even at Selection 1) ten or twenty acres of roots on a 72-acre farm will immediately suggest possible difficulties in handling the peak periods of labour need, even with a regular labour force of two men and a lad. It would be wise to take a look at a "labour profile" compiled from standard "labour requirement" data and discuss the implications of this with the farmer. Could potato harvesting be started in September and beet harvesting be delayed until November? Late beet harvesting will be dependent in part on enterprise selections after No. 2. If livestock come in rather than corn and the beet tops are needed for feeding them, a late start may be difficult.

In the variable costs for beet and potatoes a total of £171 for casual labour on the twenty acres has been allowed. Is this enough, or would it be better to spend a bit more to ensure that regular labour was available for other farm enterprises? If more is spent, then gross profit from roots will be reduced, but this reduction might be more than offset by the gain from being able to handle a 20-cow dairy herd in preference to either sheep or corn.

Every week of labour taken away from root harvesting will mean a reduction of about ½-acre for potatoes or approaching an acre for beet —a loss of £35–£40 of gross profit. Would more be earned by taking this labour from roots to allow some other enterprise to be undertaken, or is investment in mechanized root harvesting a better answer?

Perhaps at *Selection* 3 the idea of a 72-acre farm with 20 acres of roots and a 20-cow dairy herd with yet a further 16 acres left for either sheep or corn may seem unduly intensive. This is a good reason for trying the effect on the programme selection of reducing the regular labour to two men or even one man—dividing the enterprise gross profits per acre by the labour requirement per acre and ranking them for selection in descending order of gross profit per hour or per man-day.

At *Selection* 4 some perfectly valid objections to sheep may be brought forward. Having regard to earlier selections, sheep may not be very satisfactory due to shepherding difficulties and inadequate grazing control. If this is so, each acre taken from sheep and transferred to corn will reduce gross profits by something less than £2. Having regard to the variability of much of the data on which this difference of gross profit depends, it cannot be taken too seriously. The following programme would have certain advantages, particularly as regards the provision of straw and the cereal ingredients of the cows' rations.

	Crop	*Acres*	*Gross Profit*
			£
Selection 1	Potatoes	10	702
" 2	Sugar Beet	10	409
" 3	Cows (20)	36	1,353
" 4	Corn	16	400
		72	2,864

A specimen labour profile for this programme is set out in Appendix III, and its implications would need to be considered in relation to the particular circumstances of the farm.

The programme has been planned on the basis of dairy heifers being bought in at £100 each and fetching £40 after a 3-year herd life. Rearing something like 6 heifers a year would clearly need to be considered. If the variable costs of taking a heifer calf to $2\frac{1}{2}$ years were £50 with a land requirement of 2 acres, then the gross profit per acre would be £25.

Among the considerations affecting this decision then would be the fact that land taken from corn for rearing would not affect total gross profit, but land so taken from milk production would reduce gross profit by some £11 per acre.

An estimate of net farm income requires that fixed costs be deducted from the total gross profit of the completed Programme.

Such then is the basic nature of Programme Planning. It seeks to make direct use of the information gleaned by record and account analysis and farm appraisal to build up an appropriate schedule of variable costs and gross profits for possible enterprises. It then attempts to use this information in the light of technical knowledge and the rules of good husbandry to guide enterprise selections and decisions on their size and method to secure the greatest long-term cash margin over costs that the farm resources can achieve.

Appendix I: Crop Gross Profits

Enterprise	Yield	Price	Gross Income	Variable Costs: Seed	Fertilizer	Casual Labour	Fuel	Spray and Haulage	Total	Gross Profit per Acre
			(a)						(b)	(a less b)
		£ s.	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.
Potatoes . .	10 tons	12	120	15	16	10 2	5 14	3	49 16	70 4
Sugar beet . .	12 tons	6 5	75	1 2	14	7	3	9	34 2	40 18
Wheat . . .	25 cwt	29	36 5	2 15	2 16	2 2	1 16	1	10 9	25 16
Barley . . .	25 cwt	28	35	2 14	2 10	2 2	1 7	1	9 13	25 7
Oats . . .	25 cwt	27	33 15	3	2 10	2 2	1 13	1	9 5	24 10

Appendix II: Livestock Annual Gross Profits

Enterprise	Yield	Price	Gross Income	Variable Costs: Concentrates	Grass	Replcm't Cost	Misc.	Total	Gross Profit	Acres/Head	Gr. Profit per Acre
			(a)					(b)	(a less b)		
		£ s.	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.		£ s.
Cows . . .	800 gal + calf	3 +12	132	31	8 7	15	10	74 7	57 13	1·8	37 12
Sheep . . .	1½ lambs + wool	6 + 1 10	10 10	0 10	1 3	1 10	0 12	3 15	6 15	¼	27
Beef	9 cwt + Calf Subsidy	8 + 9 5	80	16 10	9 10	15	5	46	35 5	1·8	19 10
Sows . . .	16 weaners	5	80	45	—	6	2	53	27	—	—
Poultry (100 birds) .	1,500 doz. eggs	3s. 6d.	262	160	—	40	5	205	57	—	—

Appendix III: Labour Profile (hours)

Enterprise	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Gross Profit
													£
10 acres Potatoes . .	100	100	120	190	120	—	50	—	—	680	190	—	702
10 acres Beet . .	30	30	30	100	130	310	130	—	—	100	360	140	409
36 acres Milk:													
20 Cows . .	300	300	300	280	220	160	220	220	220	240	280	300	1,353
20 acres Grazing .	—	—	5	20	3	—	—	—	—	—	—	—	—
16 acres Silage .	—	—	32	16	—	96	—	—	32	—	—	—	—
16 acres Corn . .	—	—	16	16	16	16	16	48	160	—	—	32	400
Totals . .	430	430	503	622	489	582	416	268	412	1,020	830	472	2,864

A New Approach to Group Advisory Work

ALLAN W. STOBBS

National Agricultural Advisory Service, Durham

IT WAS the writer's good fortune to spend a year at Michigan State University as a Fellow of the W. K. Kellogg Foundation. One of the features of this Land-grant University is the annual "Farmers Week", when all the diverse activities of the State Extension Service are brought to a climax.

For one week, the University campus is at the disposal of farmers and farming organizations. The days are devoted to meetings, conferences and demonstrations on new developments and techniques in farming and home-making, while the evenings are utilized by farming organizations such as the Grange, Farmers' Union, Breed Societies, and Dairy Herd Improvement Societies for their Annual Banquets. Hostel facilities are available so that both husbands and wives can participate fully in the week's programme.

Need for Basic Knowledge

This "Farmers Week" idea seemed an excellent way of getting over information on a specific subject to the people most vitally concerned. Could not the N.A.A.S., County Durham, England, do something similar to the Extension Service, Michigan, U.S.A., even if on a much less ambitious scale?

When discussing with farmer friends the points raised at a meeting or conference, it has often been noticed that they have failed to understand what the speaker had to say because they lacked the necessary foundation of basic knowledge. Even today, there are many farmers who do not understand the meaning of "Starch Equivalent", yet very rarely do speakers on "Livestock Feeding" and kindred subjects remind their audiences of the definition of S.E. Probably most of us tend to assume that *all* farmers have had a basic education in what might be called agricultural technology. One beneficial outcome of the Small Farmer Scheme is that it has rudely shattered this fallacy!

How Could the N.A.A.S. Help?

With the science and practice of farming becoming more and more technical as each year goes by, could not the N.A.A.S. do something positive to strengthen these occasionally shaky foundations of basic knowledge?

Further thought produced a formula for a new kind of approach in group activities. Its composition had to be:

a single subject;
complete coverage of that subject;
an audience vitally concerned with the subject;

the presentation of facts rather than opinions;
a "residential" atmosphere with meals provided.

Why "Academy"?

A title was required that would connote the sort of thing we had in mind yet distinguish it from the more conventional meeting, conference, or course. "Academy" was the choice—a word used more often in Scotland than in England, but appropriately defined as "a school for instruction in special subjects". Our working definition became: "An Academy is an intensive one-day course on the basic facts of a particular agricultural subject". This appears on all the invitations.

Organization

If an Academy is to be successful, the preparations must be thorough. Attention to the following details is vitally important.

CHOICE OF VENUE

In deciding where to hold an Academy consideration must be given to:

Geographical position.
Size and shape of the meeting room.
Provision of light, both natural and artificial.
Provision of comfortable chairs and adequate table (or desk) space.
Heating and ventilation.
Proper facilities for showing films or lantern slides (the blackboard also plays an important part in the proceedings).
Provision of a good meal at the right time and at a reasonable cost, preferably in an adjacent room.

In each area of the county we have been fortunate in finding a suitable hotel, with the required accommodation.

PUBLICITY

It was decided that the numbers attending an Academy should be limited to thirty; experience has since shown this to be just about right. The difficulty was to publicize the event sufficiently to get thirty applicants, but not so well that many more applied. One method would be to select farmers who would be sent personal invitations, but this system would open the door to charges of favouritism. Press advertisements, on the other hand, reach a wide audience but do not discriminate between the professional "go-to-meeting" man and the farmer who is genuinely interested in the subject.

As a compromise, we posted a personal invitation to all farmers in a limited number of parishes. These invitations stated clearly that accommodation was restricted to thirty and that the first thirty to apply would be accepted. A specimen invitation is set out overleaf.

SPECIMEN INVITATION

PRESENTING A NEW IDEA

The climate of the North of England is probably more suited to the growing of grass than to any other crop and yet the least productive part of the farm is often the grassland. Because of this, and the increasing demand in this area for more information about grass production, it has been decided to run a "Grassland Academy".

This "Academy" will be a very intensive one-day course on the rudiments of grassland husbandry and for this reason it is necessary to limit the number attending to thirty.

If you wish to attend, the attached application slip should be completed and returned *at once*. The first thirty applicants will be accommodated and if more than that number apply a further "Academy" will be arranged.

Lunch will be provided at a charge of 7*s*. 6*d*.

Allan W. Stobbs,
District Advisory Officer

Complete and return to Elvet House, or telephone Durham 4433 (Extension 114) before 16th January, 1958.

Please reserve....places for the "Grassland Academy" to be held at the Cleveland Arms, Middleton, on Thursday, 23rd January, 1960.

I understand that lunch will be provided and that the inclusive charge will be 7*s*. 6*d*.

Name..................................

Address...............................

REVERSE SIDE OF INVITATION

PROGRAMME

9.45 a.m.	Registration.
10.00 a.m.	Introduction.
10.05 a.m.	Varieties and strains of grasses and clovers.
10.25 a.m.	Seeds mixtures.
10.45 a.m.	Questions.
11.00 a.m.	Preparing the seedbed and methods of sowing.
11.30 a.m.	Questions.
11.45 a.m.	Feeding the plant.
12.15 p.m.	Questions.
12.30 p.m.	Lunch.
1.45 p.m.	Methods of grass conservation.
2.30 p.m.	Questions.
2.45 p.m.	The utilization of the growing crop.
3.15 p.m.	Break.
3.30 p.m.	The utilization of the conserved crop.
4 00 p.m.	Questions.
4.15 p.m.	The place of grass on the farm.
4.45 p.m.	Questions.
5.00 p.m.	Disperse.

SPEAKERS

S. Campbell, B.Agric.	Regional Grassland Officer
H. B. Huntley	Regional Machinery Officer
N. Trinder, M.Sc., A.R.I.C.	Regional Nutrition Chemist
A. W. Stobbs, B.Sc., M.S.	District Advisory Officer

Results over the past three years show that some 500 invitations should be sent to produce thirty replies within a reasonable space of time. Not a very good response, perhaps, but a consistent one. One exception was an Academy last February on "Seed Potato Production" when, for obvious reasons only those known to be interested in the subject were invited. Thirty-four invitations were sent; 32 farmers subsequently attended.

Planning the Programme

The appropriate county and regional staff always hold a preliminary meeting, at which the subject is broken down into seven or eight parts, each part being allocated, as far as possible, to a different speaker. The Regional Specialists have been extremely co-operative at these meetings, allowing themselves to be bullied and brow-beaten into confining their talks to precisely what the programme required.

We also insist that District Advisory Officers take an active part in lecturing. This has proved to be a valuable discipline, for to speak with authority on a subject it is necessary to spend some time in getting up-to-date on current information—an exercise which may tend to be neglected in the hurly-burly of normal day-to-day work! At these staff meetings a time-table is also prepared of the events of the day, and this is strictly adhered to, for it is fatal, in an activity of this kind, to allow a speaker to over-run his allotted time.

Supplementary Material

An intensive one-day course of this kind could lead to acute mental indigestion for those attending. Accordingly, everyone was given a loose-leaf folder containing summaries of each talk and a copy of appropriate Advisory Leaflets. The summaries were interspersed with blank sheets of paper, for individual notes. This material plays an important part in creating the right atmosphere for the Academy and effectively breaks down any shyness or reticence that anyone may have about taking notes.

Farmers who attended have confirmed that they referred to their notes afterwards, and if not satisfied, would invariably make a request for further information.

Response

This project was embarked upon with considerable doubts about its reception by the farming community. Some said that farmers would be insulted by the suggestion that they should "go back to school". Others thought that the whole idea was too theoretical and would have no appeal to the practical man. Both these fears have proved to be groundless. Far from being insulted, the farmers who have attended them have been fascinated at the very idea of "going back to school". Perhaps we underrate the desire of many farmers to make up now for earlier omissions in their education—although they may not always be prepared to admit this in public.

Be that as it may, in 1957–8 we planned two "Grassland Academies", and ended up by holding three because of popular demand. This year, 1959–60, we have held four "Potato Academies", and all have been very successful.

Although most farmers attending these academies have been previous clients of the N.A.A.S., about 10 per cent were people with whom we have had no regular contact. Furthermore, this kind of activity enables us to keep in touch, or regain contact, with men who would otherwise have been neglected.

As with all kinds of educational work it is extremely difficult to assess the real value of this method of approach. Much of the effect may be indirect: e.g., since academies were held on "Grassland" and "Seed Potato Production", both a Grassland Society and a Seed Potato Grower's Association have been formed in the County.

As a tool for the adviser, the "Academy" is liked because it is so very positive in getting information across. The message can be transmitted directly from source to receiver without any waste or loss on the way. It is almost as effective, though much less time-consuming, than the individual farm visit. In these days when much of our time is occupied by the Small Farmers Scheme, any method by which the N.A.A.S. can continue to serve those who do not qualify under that Scheme is worthy of consideration. For these reasons, the Academy is to be recommended.

Crook-root Disease of Watercress

A review of research

J. A. TOMLINSON

National Vegetable Research Station, Wellesbourne, Warwick

IN 1947 a hitherto unobserved disease of watercress was seen by officers of the N.A.A.S. in a watercress bed in Wiltshire. The plants were stunted and their roots were curled and "crooked" in a very characteristic fashion (Plate I (top)). The name of "crook-root" was thus given to the disorder, but the cause and infectiousness of the disease was not established until 1951 when Spencer and Glasscock[1] showed it to be due to a species of *Spongospora*. The fungus has since been classified on morphological grounds[2] as a form of *Spongospora subterranea* (Wallr.) Lagerh., the cause of powdery scab of potatoes. It differs from this fungus, however, in that the crook root fungus does not infect potato and conversely the powdery scab fungus does not infect watercress.

Early Theories

One of the most surprising features of the disease was its widespread distribution. This was mainly responsible for a number of theories that were first put forward to account for the damage it caused to watercress. It was at first difficult for growers to appreciate that the root distortion was responsible for the lack of vigour and eventual death of plants. It now seems clear, however, that even minor disturbances of the root system of a plant which is growing in such a dilute nutrient as that supplied by artesian water will easily cause deficiency symptoms to appear on the leaves. Such deficiency symptoms are in fact a notable feature of the disease.

All the various theories attempted to explain the apparently sudden appearance of the disease over the whole of Southern England. This was, and still is, difficult to account for, when it is remembered that the fungus spends most or all of its existence in the water of individual, and often isolated, watercress beds. An even more surprising feature is the occurrence of the disease in wild watercress, often many miles from commercial beds (e.g., one such outbreak occurred in the famous Charlecote Park near Stratford-on-Avon). Thus, although some of the spread of the disease can be attributed to the distribution of infected cuttings, this is by no means the whole story and there must be some other agency for the dissemination of the fungus. It has been suggested, for instance, that the birds which frequent watercress beds may carry infection with them.

Although at first an exclusively British disease, crook-root has now appeared in Belgium[3] and France,[4] where it seems likely to become of increasing importance.

Causal Fungus

In spite of the early theories it is now known, both from the early work of Spencer and Glasscock[1], and from later research, that the *Spongospora* root infection alone can account for all the disease symptoms. Work has therefore been concentrated on attempts to rid the beds of this fungus and thus produce healthy crops.

The fungus closely resembles that causing clubroot (*Plasmodiophora brassicae* Woron.). It produces zoospores which penetrate the outer cells of the root and develop within them into the protoplasmic masses termed plasmodia. The cells swell and proliferate with the consequent distortion of the roots. Within a few days each plasmodium segments and then forms large numbers of sporangial sacs (Plate I (bottom)) from which more zoospores are released into the water through a hole in the cell wall. The whole cycle is completed in less than ten days, and in conse quence, the water in the watercress bed becomes copiously charged with swimming spores and the rate of infection of healthy watercress becomes progressively greater.

During the summer months resting spores are produced within the root tissue in sponge-like masses known as spore-balls. The function of these spore balls is obscure. Repeated attempts to induce them to germinate have failed, and although it seems possible that they may represent a resistant stage in the life-cycle of the fungus, which enables it to persist in the watercress beds from one crop to the next, this is unproven.

Field Symptoms

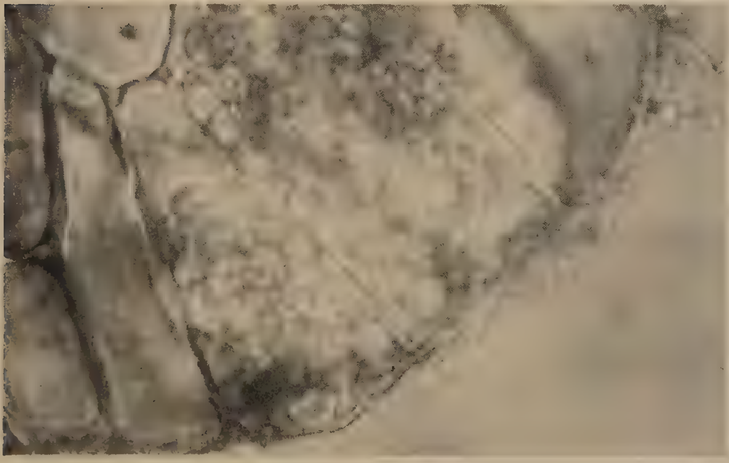
Watercress is normally grown in rectangular beds 300–600 ft long and 20–40 ft wide, the floors of which are composed of gravel, silt or chalk. The beds are fed with spring water, which may come from considerable depths and which flows at the rate of 300,000–500,000 gal per acre per day. Its temperature at source is 50–52°F and it is usually alkaline.

A group of beds may be fed from a single large spring or borehole, the water being diverted through suitable channels, but sometimes each bed has its own spring or group of springs, often arising within the floor of the bed. As will be shown later, these features are of considerable importance in the consideration of control methods.

In the summer the beds are planted with cuttings or sown with seed. By October the watercress is usually well-established and it is normally from this time onwards that the disease begins to manifest itself. The first sign of trouble is usually a weakening and thinning of the plants toward the outlet at the lower end of the bed. The weakened plants often show severe deficiency symptoms and may be bluish or yellow in colour. This decline may become obvious further up the bed as the autumn progresses until by January–March the bottom two-thirds of the bed may contain nothing but a few weak plants. Those in the top

CROOK-ROOT DISEASE OF WATERCRESS (See pp. 13–19)

Above: Healthy watercress system.
Below: Watercress root system affected by crook-root.



Section of a watercress root system showing the sporangial sacs (zoosporangia) of the crook-root fungus in two of the outer cells of the root.

PLATE I

Left: Untreated watercress bed affected by crook-root.
Right: Watercress bed treated with zinc frit.

PLATE II

few yards of the bed near the water inlet, however, usually remain vigorous and comparatively free from root symptoms.

A good deal of survey work had to be done in the early part of the research to establish that the progressive decline in plant vigour was in fact associated with an increase in root infection. Even when this was demonstrated the distribution of the disease in the watercress bed remained puzzling, until it was shown that the effect was related to zoospore concentration[5] which was at a minimum in the parts of the bed nearest to the fresh water supply.

The damage caused by the disease is influenced by weather conditions. Thus, after frost, healthy watercress will normally recover and recommence vigorous growth on the return of milder weather. Infected plants, however, may remain stunted, an effect which may be enhanced after cutting or pulling the crop. Conversely, the effects of the disease are less apparent in mild winters and, during the summer, even those beds which are severely affected may contain a fair quantity of watercress.

Laboratory Experiments

Spencer[6] working at the N.A.A.S. sub-centre at Wye first showed that healthy plants could be infected by growing them in jars of spring water containing detached infected roots. This simple technique provided the basis for most of the studies that followed, although later it was found more suitable to use complete diseased plants instead of detached roots as a source of infection.

Using this method it was possible to demonstrate that the bicarbonate content of the water profoundly affected disease transmission.[5] Thus, whereas infection occurred readily in water from watercress beds containing about 350 p.p.m. total bicarbonate (Ca & Mg), it was almost completely eliminated if the bicarbonate content was increased to 500 p.p.m. It was at first thought that this might provide a basis for control and one field test was made in which good control was obtained. The method proved uneconomic, however, and was abandoned in favour of other and cheaper methods.

The laboratory test was later used in trials of fungicides and is still in use for many of the basic experiments. In one important respect the test pointed the way to the means whereby the disease could eventually be controlled. This resulted, surprisingly enough, because of a succession of failures to transmit the disease in a series of trials. These were originally made by Spencer, and later by the author, using the laboratory tap water at Wye N.A.A.S. sub-centre. In this water the disease consistently and completely failed to be transmitted, although as already noted, ready transmission occurred in spring water.

Chemical analyses of the two waters did not reveal any obvious differences between them and it was not until they were analysed spectrographically by Dr. R. L. Mitchell of the Macaulay Institute that it was found that the tap water contained minute traces of zinc. The

amount was so small—1·8 p.p.m.—that it seemed difficult to believe that it could affect the disease so profoundly, but subsequent tests showed that this was so. The fortunate chance, therefore, that the laboratory taps at Wye were supplied through a galvanized iron pipe, several hundred feet long from which the zinc was dissolved, enabled the extreme effectiveness of the metal against the disease to be demonstrated. Later experiments showed that the zinc prevented transmission by killing the zoospores. Sections of diseased roots were placed in distilled water when they emitted clouds of swimming spores which remained active for periods up to 30 minutes. On replacement of the water with a solution of zinc sulphate containing 1·0 p.p.m. zinc, however, the zoospores ceased movement, became rounded off and died.

Preliminary Field Experiments

The work on zinc was, of course, only a part of a larger project, but after reviewing various other possible means of disease control, it eventually appeared that the use of zinc might provide the most satisfactory one. As in all such work, however, the problem of translating laboratory results into field trials had still to be overcome, with the added complication that the use of fungicides in water was a comparatively unexplored field.

Spencer and Glasscock and some others had investigated the possibility of placing bags containing relatively insoluble fungicides in watercress beds but the tests failed because the plants were killed or stunted. The same result was obtained in some of the author's experiments using chlorine.[7]

It thus appeared that the main requirement was a means of distributing zinc throughout a watercress bed in such a way that the water would contain about 1·0 p.p.m. zinc for at least a major part of the growing season. It was also necessary to find a method that was applicable to all types of watercress farm, whether the beds were fed from a central source or from many springs.

With these requirements in mind, a search was first made for an almost insoluble zinc-containing material which could be applied to the floors of the beds and which would release zinc only very slowly. This search proved fruitless until the author's attention was drawn to some research done in America on the supply of trace elements to soil by means of a glass "frit", a finely powdered glass containing the necessary metals.[8] With the co-operation of a firm of enamel manufacturers a zinc frit was therefore made. Laboratory tests showed that it would control infection if supplied in quantities as low as 0·05 g per 350 ml water.[9] In view of this encouraging result field tests were made in a range of experimental beds constructed by Mr. J. B. Jesty at Bere Regis, Dorset, and freely loaned for our use. The trials gave further promise of success and the material was then tested on a commercial scale.

In the meantime tests were in progress on the use of zinc sulphate fed into the inlet water. This was only likely to be of value where one, or only a few, boreholes or springs supplied a number of beds. Because of this limitation less emphasis was at first placed on this method of supplying zinc, but both methods are now being tested in many commercial beds.

Commercial Trials of Zinc Frit

In the early trials started in 1956 the material was applied at the rate of 1 lb per sq. yd. Tests of the zinc content of the treated watercress showed that such cress was quite safe for human consumption and the outflow water from such beds was non-toxic to trout.

The treatment controlled the disease, in some instances in a spectacular fashion (Plate II), and it appeared that a practical cure of crook-root might have been found. Unfortunately, however, it became clear in 1957 and 1958 that further applications of frit could cause iron deficiency in the plants. Such further applications were necessary because the fungicidal effect of the frit lasted only for one season. It was found that much of the frit had become incorporated in the floors of the beds from which the zinc was absorbed by the plants. Of even more importance was the fact that attempts to control the iron deficiency by the application of iron compounds could result in further absorption of zinc by the plants, to a point where amounts in excess of the maximum permitted quantity were present.

It was obvious that the treatment required modification and further tests were made, first in the experimental beds and later, when these were successful, in commercial farms. At about this time another type of zinc frit became available. This contained a higher proportion of zinc (36 per cent zinc oxide instead of 23 per cent in the original material) and was also much more finely ground. Tests with this frit showed that it was effective at much lower doses than 1 lb per sq. yd, and also that it would give good control throughout the bed even if it were applied only to the top few yards. Laboratory studies have shown that this increased effectiveness was almost certainly due to the small particle size which resulted in a greater solubility.

Trials of frits of different particle sizes and at various rates are still in progress, but it now seems possible that frits may be found which will be of practical value. This, however, can be fully tested only by trials extending over several seasons.

Commercial Trials of Zinc Sulphate

As already noted the supply of zinc in a soluble form is likely to be successful only when the whole of the water feeding a bed or group of beds can be treated. On some farms this can be done and trials have now been started on such farms after preliminary tests in the experimental beds. These early trials have been very encouraging. The disease has been eliminated within 45 days by treatments giving as little as 0·1

p.p.m. zinc in the water. For efficient treatment, two main criteria must be satisfied:

(a) the rate of application must be meticulously adjusted, the aim being to raise the zinc content of the water to 0·1 p.p.m.; and
(b) the concentrated zinc sulphate must be thoroughly mixed with the whole of the inflow.

It is also, of course, necessary to ensure that there is no danger of leakage of the concentrate since this would not only be deleterious to the watercress but might also kill fish in the effluent streams.

Bearing these requirements in mind the problem becomes largely one of water "mechanics". The water flow must be carefully measured by means of graduated weirs and the drip feed of concentrated zinc sulphate adjusted using a previously calculated formula. A turbulent mixing pool must be obtained, if necessary by constructing one especially and the whole process must receive careful daily supervision. There is no room for casual "hit or miss" methods and for this reason the full collaboration of officers of the N.A.A.S. is necessary. It is hoped shortly to develop standard equipment which can be used in sites where the method is likely to work, and by the winter of 1960–61 it should be undergoing widespread commercial trial.

Conclusion

This account has dealt briefly with the progress of a research problem from the initial discovery of the disease to the development of promising methods of control. The problem is by no means completely solved, however. More field trials extending over several years may be necessary before it will be known whether the disease can finally be controlled. Other possible methods of treatment are being tested, and at least one of these (the use of sodium hypochlorite) is being studied by other workers. The problem serves as an example of three-fold collaboration between research worker, adviser and grower which should eventually lead to a successful conclusion.

References

1. Spencer, D. M., and Glasscock, H. Crook root of watercress. *Plant Pathology*, 1953, **2**, 14–21.

2. Tomlinson, J. A. Crook root of watercress. III. The causal organism *Spongospora subterranea* (Wallr.) Lagerh. f. sp. *nasturtii* f. sp. nov. *Trans. Brit. mycol. Soc.*, 1958, **41**, 491–8.

3. Parmentier, G. Remarques sur une affection nouvelle du cresson. *Parasitica*, 1956, **12**, 138.

4. Bondoux, P. Sur une maladie du cresson, nouvelle en France. *C. R. Acad. Sci.*, Paris, 1958, **246**, 1457–8.

5. TOMLINSON, J. A. Crook root of watercress. I. Field assessment of the disease and the role of calcium bicarbonate. *Ann. appl. Biol.*, 1958, **46**, 593–607.
6. SPENCER, D. M. Watercress investigations. *Rep. Nat. veg. res. Sta.*, 1950, 52–6.
7. TOMLINSON, J. A. Crook root of watercress. *Rep. Nat. veg. res. Sta.*, 1957, 60–1.
8. WYND, F. L. Availability to wheat plants of iron in very insoluble glass frits. *Lloydia*, 1951, **14**, 1–33.
9. TOMLINSON, J. A. Crook root of watercress. II. The control of the disease with zinc fritted glass and the mechanism of its action. *Ann. appl. Biol.*, 1958, **46**, 608–21.

The Place of the Nodulated Legume in Agriculture

P. S. NUTMAN

Rothamsted Experimental Station, Harpenden, Herts.

Symbiotic Nitrogen Fixation under Natural Conditions

THE SIGNIFICANCE of the legume symbiosis in the nitrogen economy of nature or agriculture is difficult to overestimate. The leguminosae is one of the largest families of flowering plants, surpassed in number of species only by the compositae and by the orchidaceae, which is also symbiotic. Its 12,000 cosmopolitan species range from herbs to forest trees and must far outclass all other natural agents which fix atmospheric nitrogen, whether symbiotic or free-living.

The amount of nitrogen fixed by legume crops and in pastures has often been estimated. The following examples show the amounts which may be fixed in pounds of nitrogen per acre per crop or season: lucerne, 50–350; clovers, 50–200; peas, 30–140; pastures with legumes, 10–550.[17,1,2] These ranges are much greater than those coming from uncertainties in estimation. Errors of measurement can now be decreased using special methods such as N_{15} isotopic analysis and by the field comparison of normally nodulating and selected non-nodulating varieties of the host.[10] It is to be hoped that new and more reliable estimates will soon be forthcoming.

The benefits of fixation, as well as their seemingly inevitable fluctuations, tend to be taken for granted. If fixation is so low as to constitute an agricultural problem, remedial measures are taken by management or fertilizer treatment or by inoculation with nodule bacteria. (For literature on legume agronomy and nutrition see White *et al.*[19] and Hallsworth,[9] and for recent trends in inoculation practice see van Schreven *et al.*[15] and Vincent.[16]) When there are no obvious nitrogen deficiencies, large differences in fixing potential may easily go unnoticed. Whatever their cause, the striking variations in fixation in the field are an agricultural challenge. Faced with this situation, it may be worth while to consider the possible causes of variation in amount of nitrogen fixed.

In a short article it is not possible to review all recent work relevant to this topic and two aspects only will be considered: the problem of ineffectiveness in nitrogen fixation in an established symbiosis, and the related problem of the biochemistry of the fixation process in the normal effective nodule.

Variation in the Symbiotic System

At one time ineffectiveness was considered to be wholly a property of the bacterial strain, but the discovery that strains can be ineffective in

one host species but quite effective in another, showed that effectiveness cannot be so simply defined. The separation of bacterial strains and hosts within a cross-inoculation group into sub-groups, based on symbiotic response, has been of practical value in deciding the best strains to use in seed inoculation, particularly where inoculation may be crucial for establishment, as with subterranean clover in some parts of Australia or with white and red clover on new polders in Holland. Most bacterial strains that are fully effective on red or white clover are partially or wholly ineffective on subterranean clover. When subterranean clover was first inoculated, an inoculum of strains originating from red clover was often used, with consequent poor results. Much still needs to be done on host-strain specificity within the cross-inoculation groups, particularly those containing a wide range of species.

The differences shown when various host species are inoculated with a common bacterial strain reflect the influence of host genetic control, but hybridization between species is generally impossible so the ordinary methods of genetic analysis fail. However, examination of individual plant differences within a species, particularly an out-pollinating one, discloses a similar pattern of variation, which is genetically complex but susceptible to analysis (for references see Nutman[13]). Not only is effectiveness in nitrogen fixation under the joint control of inherent factors in bacterial strain and host plant, but also all other features and phases of symbiosis appear to be similarly constrained. Most of the work on host genetics of effectiveness has been done with red clover and subterranean clover and discussion will be restricted to these species. Nutman[11, 12] has reviewed work on other species and on physiological correlations.

HEREDITARY FACTORS INFLUENCING NODULE FORMATION IN RED CLOVER

In red clover only one kind of hereditary resistance to infection has so far been encountered. This is governed by a simple recessive factor acting in conjunction with a cytoplasmically transmitted component; it is very uncommon in commercial seed. In normal plants the first nodules form at about the spade-leaf stage of seedling development, but the time at which the first nodule is formed and the subsequent rate of nodule formation vary greatly. Early and late nodulating lines of host, and lines that nodulate sparsely or abundantly, are easily selected. Both these contrasted types of nodulation are determined in the host by independent sets of polygenes. Earliness or lateness, and sparseness or abundance, are also influenced by bacterial strain; the host and strain effects acting largely independently of each other.

INHERITANCE OF SYMBIOTIC EFFECTIVENESS IN RED CLOVER

The inheritance of symbiotic effectiveness in red clover is complex and only partially known. Some of the host factors controlling the efficiency of the nitrogen fixing and assimilating processes are polygenic and independent of bacterial strain. Others are simple and show dominance and may reveal themselves only with certain strains. The simply

inherited defects are the more interesting, because each appears to divert normal effective development at a particular stage and to have easily recognized side effects. One such recessive host factor interferes with the growth of the bacteria immediately they are discharged from the infection thread and has concomitant effects on the infected plant cell; the invaded host cells continue to divide instead of immediately maturing as in the normal nodule. The gross morphology of the nodule is little affected, but the cells of the infected central tissue are irregularly shaped and much smaller than usual. The anatomy of these nodules resembles that of a plant tumour.

Another recessive host factor affects the symbiosis at a later stage. The bacteria multiply normally within the host cell but they do not develop into the bacteroids. This gene clearly acts at a later stage in the normal sequence of events than the one responsible for tumourization. Neither of these recessive genes operates against all bacterial strains and their consequence in producing ineffectiveness can be overcome by inoculating with strains that are effective in plants with such genes. In one instance ineffectiveness has been circumvented by variation in the test strain of the bacterium itself.

Undoubtedly variations in other features of the symbiosis will be found to express underlying genetic diversity in the host. Casual observation already suggests that variation in nodule size, shape, colour, longevity and position on the root are all hereditarily determined.

SYMBIOTIC VARIATION IN SUBTERRANEAN CLOVER

A parallel study of symbiotic variability is being made in subterranean clover (Nutman[13] and unpublished data). This legume is an important annual pasture legume introduced in Australia. It belongs to a different subsection of the clover cross-inoculation group and contrasts sharply with red clover in several ways. It has a very different breeding habit in that it is self-pollinated instead of self-sterile. It occurs in a wide range of distinct varieties, each of which is practically isogenic and very homogenous in every respect, including symbiotic behaviour. The genetic basis of effectiveness is much more uniform throughout the species, even more so than within single families of red clover. Attempts to modify effectiveness by selection after artificial hybridization all failed. The varietal differences noted in the time of primary nodulation are all small, but the number of nodules formed by different varieties of subterranean clover varies greatly. As in red clover, nodule abundance in the host is polygenetically determined and largely independent of bacterial strain, but unlike red clover, which shows only a broad inverse correlation between nodule size and density, nodule size in subterranean clover is related to abundance in a clearly defined way. This relation is such that the product of plant nodule number and average nodule length is constant for any one variety, and is maintained with strains of bacteria which differ in the number of nodules they produce, provided that they are of equal effectiveness. Nodule length is highly correlated with nodule

volume, so that this relation ensures a constant volume of nitrogen-fixing tissue, no matter how this may be distributed between nodules. It also means that the amount of fixation is accurately adjusted to the plant's requirements; small numbers are compensated by large size. In red clover the exact form of the relation between nodule size and number is obscured by the confusing effect of many other factors.

EFFECTS OF DIFFERING CONDITIONS

In consequence of this compensating mechanism the many varieties of subterranean clover found in Australia all have the same potentiality for nitrogen fixation. In Australian soils, nitrogen levels tend to be low so that the survival of plants is primarily determined by their total capacity to fix nitrogen. Under one set of conditions it may be better for the fixing potential to be widely spread throughout the root system, and in another to be more concentrated. Now that nodule size and abundance can be controlled, these alternatives can be studied.

Nodule bacteria in culture, and in the field, give rise sporadically to variants that are ineffective for their normal host or even lose altogether their capacity to invade the root. The nature of changes of this kind, and their manipulation by mutagenic agents, etc., is now being studied in several places. This work is only at an early stage, but it should eventually lead to the better control of strain and possibly also to the breeding of bacteria best suited to any particular host or conditions.

The long-term objective of all these investigations is to describe as completely as possible the sources of variation in host and bacterium, to determine their genetic basis with the aim of controlling them by breeding, and to discover the underlying physiological or biochemical mechanisms.

The usefulness of this information to the agriculturalist is hard to assess. The activities of host and bacteria are so complex and interact so closely that the manipulation of the symbiosis presents serious problems to the plant breeder. There is no reason to suppose that nitrogen fixation by crop plants cannot be increased by breeding, but the rationalization of a breeding programme requires recognition of the nature of the factors concerned.

Mechanism of Nitrogen Fixation

That nitrogen is fixed in nodule cells containing the bacteroids and the pigment haemoglobin has long been known, but until very recently it was not known whether fixation occurred within or on the surface of the bacteroid, or in the plant cytoplasm, or whether the process was essentially oxidative or reductive. What evidence there was suggested that the bacteroid was the responsible agent and that the process was reductive. Recent work in Australia and the U.S.A. appears to have settled both these questions. The first step in the identification of the intracellular site of fixation was the demonstration (by electron-microscopy of nodule sections) that the bacteria escaping from the infection

threads into the nodule cell become enclosed, individually or in small groups, within folds of the outer cytoplasmic membrane of the host cell. The bacteria multiply a few times within these membranes before they are transformed into bacteroids. The mature infected host cell in this way comes to contain an intricate system of membranes of plant origin, each fold of which encloses a small group of bacteroids.[4] By differential centrifugation the membranes of crushed nodules can be separated from the bacteroids and from the rest of the cytoplasm.

EARLIER ASSUMPTIONS ON NITROGEN FIXATION PROBABLY WRONG

In recent work on fixation, nodules were exposed to N_{15} for varying short intervals of time, then crushed and analysed. This showed that the plant membrane fraction is the first to become enriched with N_{15}, followed by the "soluble" host cytoplasmic fraction and lastly the bacteroids. These results clearly suggest that nitrogen is fixed neither in nor on the bacteroid, as had been assumed for so long, but on a structure of indisputably plant origin.[5] Independent evidence leading to the same conclusion was earlier obtained by Turchin,[14] who reported that greater isotopic enrichment occurred in the general cytoplasm of the host cell than in the separated bacteroids.

It has long been thought that the nodule haemoglobin may be concerned in fixation, acting as a reducing agent (for earlier literature see Virtanen[18]). This idea was much strengthened by the work of Hamilton, Shug and Wilson,[8] who showed spectroscopically that the haemoglobin in sonic extracts of whole nodules is oxidized to haemiglobin in an atmosphere of nitrogen. The oxygen tension inside nodules is very low, and under these conditions the haemoglobin acts as an oxidation-reduction catalyst rather than oxygen carrier. This change in the pigment was confirmed by Bergersen and Wilson,[6] who also demonstrated the simultaneous fixation of nitrogen *in vitro* and the reversible nature of the change in pigment. The addition of bacteroids to their preparations changed the haemiglobin to haemoglobin, thus completing the cycle.

The close connection between the terminal respiratory system of the bacteroid and haemiglobin reduction is also indicated by the work of Appleby and Bergersen[3] and Falk, Appleby and Porra[7]. By progressively disrupting bacteroids, they showed that the cytochromes are located on the bacteroids' plasma membrane so that "direct electron transfer between the cytochrome system and the extracellular leghaemoglobin could be postulated".

Study of the cytochromes showed that effective bacteroids contain cytochromes *b* and *c*, whereas those from ineffective nodules and from bacteria in culture contain cytochromes *a*, *b*, and *c*. The loss of cytochrome *a* in bacteroids thus coincides in time with haemoglobin synthesis, although it is not known whether the bacteria may contribute in some way to haemoglobin synthesis as they are transformed into bacteroids.

The capacity of nodule preparations, bacteroids, etc. to synthesize porphyrin from certain precursors has also been studied by these authors. The complete synthetic pathway is present in the young effective nodule, but is lost as the nodule matures and does not exist in the ineffective nodule.

The long-suspected central role of haemoglobin in nitrogen fixation now seems established. Although contained in a plant membrane the crucial catalytic function of haemoglobin depends on bacteroid respiration.

This series of studies represents an important advance. Although the process of fixation still cannot be described in precise chemical terms, in that the first intermediates are not known, the questions which the biochemist will now be able to ask will be altogether more apt.

Future Prospects

However interesting and important they may be, these new discoveries are unlikely to be the basis of a new nitrogen-fixing industry, and only in the long run may they affect our ability to control fixation. Nitrogen can already be cheaply fixed by chemical industry, but root nodules retain and are likely to increase their importance because they fix nitrogen in the field when and where required, and in doing so free the farmer from the costs of artificial nitrogen fertilizers. Application of such fertilizers to legumes is economic in some circumstances, and for certain ends, for example to increase early spring production in clover pastures in highly productive dairying areas near sources of fertilizer supply and distribution. Elsewhere, the symbiotic and free-living nitrogen-fixers will continue to provide the greater proportion of nitrogen used in plant growth, and it is in increasing the efficiencies of these processes and in extending the use of legumes that a large contribution towards higher fertility and production remains to be made.

References

1. Albrecht, W. A., Allen, O. N., Appleman, M. O., Erdman, L. W., Hofer, A. W., and Sears, A. H. *Handbook of Biological Data*, Sanders, 1956.
2. Allen, E. K., and Allen, O. N. Biological aspects of symbiotic nitrogen fixation. *Handbuch der Pflanzenphysiologie*, 1958, **8**, 48.
3. Appleby, C. A., and Bergersen, F. J. Cytochromes of Rhizobium. *Nature, Lond.*, 1958, **182**, 1174.
4. Bergersen, F. J., and Briggs, M. J. Studies on the bacterial component of soybean root nodules: cytology and organization of the host tissue. *J. gen. Microbiol.*, 1958, **19**, 482.
5. Bergersen, F. J., and Wilson, P. W. The location of newly fixed nitrogen in soy nodules. *Bact. Proc. Amer. Soc. Bact.*, 1959a, **59**, 25.
6. Bergersen, F. J., and Wilson, P. W. Spectrophotometric studies of the effects of nitrogen on soybean nodule extracts. *Proc. N.A.S. Amer.*, 1959b, **45**, 1641.

7. Falk, J. E., Appleby, C. A., and Porra, R. J. The nature, formation and biosynthesis of the haem compounds and porphyrins of legume root nodules. *Symp. Soc. Exp. Biol.* Utilization of nitrogen and its compounds by plants, 1959, **8,** 73.

8. Hamilton, P. B., Shug, A. L., and Wilson, P. W. Spectrophotometric examination of hydrogenase and nitrogenase in soybean nodules and Azotobacter. *Proc. Nat. Acad. Sci. Wash.*, 1957, **43,** 297.

9. Hallsworth, E. G. *Nutrition of the legumes.* Butterworths, London, 1958, 359 pp.

10. Lynch, D. L., and Sears, O. H. Nodulation of legumes and nitrogen fixation. 1. A new tool for measurement. *Am. Soc. Agron. Abstr. Ann. Meeting*, 1952, 68.

11. Nutman, P. S. The influence of the legume in root-nodule symbiosis. A comparative study of host determinants and functions. *Biol. Rev.*, 1956, **311,** 109.

12. Nutman, P. S. The physiology of nodule formation. *Nutrition of the legumes.* Ed. E. G. Hallsworth, Butterworths, London, 87.

13. Nutman, P. S. Sources of incompatibility affecting nitrogen fixation in legume symbiosis. *Symposia Soc. Expt. Biol.* Utilization of nitrogen and its compounds by plants. 1959, **8,** 42.

14. Turchin, F. V. The role of mineral biological nitrogen fixation in the agriculture of the U.S.S.R. *Pochvovedenie*, 1956, **6**, 15.

15. Schreven, D. A. van, Otzen, D., and Lindenbergh, O. J. On the production of legume inoculants in a mixture of peat and soil. *Antonie van Leeuwenhoek*, 1954, **20**, 33.

16. Vincent, J. M. Survival of root nodule bacteria. *Nutrition of the legumes.* Ed. E. G. Hallsworth, Butterworths, London, 1958, 108.

17. Virtanen, A. I. *Cattle fodder and Human Nutrition.* Cambridge University Press, 1938, 108 pp.

18. Virtanen, A. I. The biology and chemistry of nitrogen fixation by legume bacteria. *Biol. Rev. Camb. Phil. Soc.*, 1947, **22,** 239.

19. White, R. O., Nilsson-Leissner, G., and Trumble, H. C. *Legumes in Agriculture*, F.A.O. Rome, 1953, 367 pp.

Hypomagnesaemia

(Based on a symposium held at Whitehall Place, London, on 27th October, 1959)

S. M. BODEN

National Agricultural Advisory Service, Yorks and Lancs Region

Introduction

HYPOMAGNESAEMIA appears to be on the increase in cattle and sheep, particularly in those kept on improved pastures. Increasing attention is therefore being given to it because of the serious losses which can be suffered, for although the incidence is low (2 or 3 per 1,000 in dairy cattle) there is a high death rate in the affected animals. As an aid to the understanding of the problem, and to provide information about the trends of present-day research, a conference was held in London in October, 1959, between workers from research institutes, veterinarians, nutrition and soil chemists, and others. Before dealing with the conference itself, the following paragraphs on hypomagnesaemia in general will provide a background.

Several names have been used in the past to describe the condition—"Hereford disease", "grass staggers", "lactation tetany", are some of these. However, none is sufficiently comprehensive—the disease may have been recognized early in Hereford, but all parts of the country are affected; it can occur on winter rations as well as on grass; it is found equally in bullocks and in cows, and the relation to lactation is the mere occurrence of simultaneous stresses of calving, lactation and tetany-prone spring grazings. For over thirty years it has been known that the main characteristic is a deficiency of magnesium in the blood and this—in the form of "hypomagnesaemia"—is the preferred description, although grass staggers is a useful alternative name for the condition when it occurs in cattle at grass. "Staggers" and "tremblings" (the name given to the condition in sheep) are descriptive of the symptoms of an acute attack. There is restlessness, twitching of the muscles, excitement, a staggering gait, and finally convulsions and death if treatment is not given. An acute attack is treated by injecting magnesium (and usually calcium) salts, but as the time between the first appearance of the symptoms and death can be a matter merely of minutes, it is not always possible to save the animal.

In the acute type, the fall in the level of blood magnesium from a normal figure to the point at which an attack becomes evident may take place in a day or two, and is commonly associated with changes of management such as going out to spring grass or moving from sparse summer grazings on to the autumn flush. There is also a chronic type, more commonly found in out-wintered cattle, in which the fall is much more gradual but which may reach an unsuspected danger level. Any

extra stress then causes the acute symptoms to appear. A sudden fall in temperature overnight, for example, has been known to precipitate an acute attack; and, of course, new spring grass is another potential danger.

In sheep, the acute form of hypomagnesaemia commonly follows the stresses accompanying lambing and early lactation and the change from sparse hill grazings to improved in-bye land which is usual at this time.

Although it is established that the disorder is in the end associated with a lack of magnesium in the blood, and that it can be prevented by administration of suitable magnesium salts either by injection or by the mouth, the fundamental reasons for the lack are by no means understood. Leaving this aside for the time being, something may be said about ways of increasing magnesium intake.

Intake of Magnesium from Pasture

Hypomagnesaemia may occur on pastures which contain apparently ample magnesium (thus demonstrating that it is often a conditioned metabolic upset and not a straightforward deficiency in the food), but it is clear that trouble is bound to follow if the pastures are so deficient that the needs of the animal are not met. The ability of the adult animal to mobilize the magnesium store in the bones is extremely limited, and in no way resembles the easy way in which calcium may be borrowed. Mobilization is slightly easier in young animals, which may account for the incidence in heifers being only a tenth of that in cows which have had four or more lactations. It follows that cattle are dependent on day-by-day intakes, and a surfeit one day affords no protection on later days.

The treatment of deficient pastures will depend on the state of the soil. If a lime requirement exists, magnesian limestone containing at least 30 per cent magnesium carbonate ($MgCO_3$) is needed. A quantity of calcined magnesite (commercial MgO) providing an equivalent amount of magnesium would cost about four times as much, and this material might therefore only be applied to a limited area sufficient to provide grazing during the danger period. For well-limed soils an application of kieserite ($MgSO_4 . H_2O$) or of calcined magnesium sulphate ($MgSO_4$) has been suggested, but these materials are about twice as costly as calcined magnesite per unit of magnesium. Nevertheless, their use might have to be considered, as the application of magnesian limestone or calcined magnesite to soils without a lime requirement might produce trace element deficiencies.

Direct Feeding for Immediate Results

Application to the soil is a long-term affair and benefit may not accrue until the lapse of one or more seasons. For immediate results it is imperative to resort to direct feeding, and the supplement of choice is calcined magnesite, which contains up to 55 per cent of magnesium (or 91 per cent MgO). It is considered that adult cattle should be given 2 oz and sheep up to $\frac{1}{2}$ oz per day for the duration of the critical period

(e.g., from a week before until 4 weeks after going to spring grass). The mineral can be incorporated into concentrates so that a suitable quantity of these, between 1 and 4 lb as desired, carries the necessary 2 oz.

It is an easy matter to provide such concentrates for stall-fed or parlour-fed dairy cows, and sheep may be offered them in troughs; but it is more difficult to meet the needs of out-wintered cattle which do not receive concentrates. If, however, they are given chopped roots or silage it is possible to sprinkle calcined magnesite on this, and attempts are also being made to add the mineral to herbage at the time of ensiling, although there is some evidence that fermentation quality may be adversely affected.

Lastly, magnesium-rich minerals may be offered in troughs in the field but some animals may ignore them. There is the further point that in some cases these minerals contain too little magnesium to fulfil their purpose. Some have the equivalent of only 9 per cent MgO, i.e., one-tenth of the quantity provided by calcined magnesite. A misconception may arise if the magnesium content is expressed as being equivalent to so much "magnesium sulphate", presumably $MgSO_4.7H_2O$; a content of 9 per cent MgO would be transformed into 55 per cent magnesium sulphate which, to the uninitiated, looks very impressive. On the other hand there are brands which are rich enough to supply the desired dose in a reasonable bulk and which no doubt perform a useful function.

Availability of Magnesium in Feedingstuffs

The first paper of the symposium was given by *Mr. A. C. Field*, who reported on work done at Moredun on measuring the availability to the animal of the magnesium in its food.[1,2]

There was still no sure knowledge of the cause of hypomagnesaemia which occurred on spring grass. One view was that some factor in the grass upset the normal physiological functioning. Another view was that there was a decreased absorption from the gut which could be overcome by offering more magnesium in the form of supplements. However, animals differ widely in their ability to use dietary magnesium.

Field suggested that "availability" should be defined quantitatively as the "percentage efficiency of absorption". The difficulty is that the magnesium appearing in the faeces is composed in part of magnesium that has been truly absorbed into the blood and tissues and which is finally excreted back into the intestine. There it becomes indistinguishable from material which has never been absorbed, but has simply travelled through the lumen of the alimentary canal.

If I be the amount of magnesium eaten, F be the amount excreted into the intestine and not reabsorbed (i.e., the endogenous faecal excretion), S be the amount stored in the tissues, U be the amount excreted in the urine, and finally E be the percentage efficiency of absorption, then

$$E = \frac{F+S+U}{I} \times 100$$

(This is for a non-lactating animal, otherwise another value M, the amount secreted in the milk, would have to appear in the numerator.)

Further, if it is assumed that at different levels of intake (I_1 and I_2), E does not alter and that F and S also remain the same, then

$$\frac{F+S+U_1}{I_1}=\frac{F+S+U_2}{I_2}=\frac{U_1-U_2}{I_1-I_2}$$

In words, this means that the relationship between dietary intake and urinary excretion is linear.

Linear regression equations were in fact obtained when two wethers were fed on a selection of spring herbages, some of which were taken from fields on which no hypomagnesaemic tetany had been observed in dairy cows and others from fields which were tetany prone. There was no significant difference in utilization of the magnesium by the same wether throughout the series of herbages; but the two animals differed markedly in the percentage efficiency of absorption they exhibited:

Sheep A: Urinary magnesium = 0·126 dietary magnesium—99·5

Sheep B: Urinary magnesium = 0·263 dietary magnesium—249·7

(in terms of milligrammes of magnesium per day).

The regression coefficients, expressed as percentages, are the percentage efficiencies of absorption, i.e., 13 per cent and 26 per cent approximately. The endogenous faecal loss is given by the intercepts 100 and 250 mg (approx.) for A and B respectively. This is very nearly the same as the total endogenous loss, because urinary endogenous loss is probably no more than 10 mg/day. At a 13 per cent efficiency, 100 mg could be obtained from about 800 mg of dietary magnesium, and at a 26 per cent efficiency 250 mg could be obtained from 1 g. Even this higher dietary requirement could be reached on 3 lb herbage dry matter containing 0·07 per cent magnesium (an extremely unlikely low figure). The lactating ewe on the other hand could quite well fail to get sufficient from much richer herbage. Thus a ewe putting out 270 mg. magnesium in 2 litres of milk, but with the same characteristics otherwise as wether A, would require 2·9 g magnesium. To provide this on a consumption of 4 lb dry matter, the dry matter would require to contain 0·16 per cent magnesium, and many pastures fail to reach this figure. A straightforward dietary deficiency cannot therefore be excluded as a factor in the hypomagnesaemia of lactating ewes.

Use of Radio-isotopes

In addition to the indirect method just indicated, Field has used a direct technique involving the radio-isotope Mg^{28}, two doses being required per sheep. Owing to the relatively short-lived nature of the isotope it lost half its activity between the time of preparation and the time of use, and for the same reason it could be followed directly in the faeces for only five days. However, as the ratio of the isotope to the

faecal dry matter decreased exponentially it was possible to calculate for additional days the amount remaining unexcreted.

The sheep was fed throughout on hay which afforded 0·77 g magnesium per day and the radio-magnesium was given on different occasions by different routes—once by ruminal fistula and once by injection into the jugular vein. This method gave a percentage efficiency of absorption of 25·8 and an endogenous faecal magnesium of 205 mg/day. These results agreed very well with those of the indirect method in spite of several possibilities of error. The uncertainties include the assumptions that the dietary magnesium and the Mg^{28} are freely and uniformly miscible, and that Mg^{28} arriving in the blood from the alimentary canal is excreted in the faeces to the same extent as injected Mg^{28} is excreted.

Field disagreed with those who employed the digestibility coefficient as a measure of availability. The true availability is the percentage efficiency of absorption, i.e., $\frac{F+S+U}{I} \times 100$, which acknowledges that F has performed a metabolic function before excretion. The digestibility coefficient is only $\frac{S+U}{I} \times 100$; and, since $\frac{F}{I}$ can be quite appreciable as shown by Mg^{28} studies, the coefficient could underestimate the usefulness of dietary magnesium.

Finally, he mentioned that when sheep were changed suddenly from a hay diet to one of spring herbage, there was an unexplained drop in urinary magnesium although the change involved an increase in magnesium intake. After three to five days the urinary magnesium increased to values consistent with the linear relationship. It was hoped that further work would show whether this depression was caused by an inhibition of absorption.

Another View of Availability

In opening the discussion, *Dr. J. A. F. Rook* referred to work carried out at the National Institute for Research in Dairying.[3,4] While admitting the slight underestimation, N.I.R.D. workers preferred to regard "available" magnesium as that portion of the food magnesium which was not excreted in the faeces; in effect, they accepted the digestibility coefficient as the measure. At the same time they kept a watch on the urinary excretion, taking the view that so long as this remained detectable it represented the overflow of magnesium in excess of requirements.

When cows were changed suddenly from winter feeding to grass there was usually a fall in the urinary excretion, but it was noted that when this did not reach a very low value the serum magnesium was little affected or, at any rate, remained above the tetany level. However, where serum values were so low that magnesium therapy had to be adopted the urinary excretion had diminished to about zero.

Young grass herbage was cut and offered *ad lib.* as the sole food to dairy cows, and the daily available magnesium was found to vary from

0·5 g (from an intake of 9·6 g) to 4·2 g (from 15·2 g). The corresponding daily urinary outputs were 0·0 and 0·2 g respectively, and the serum levels were below 1·0 and above 2·0 mg/100 ml. Magnesium intakes and availability on winter rations were twice as high, and hypomagnesaemia was absent, but wide variations were observed in the availability of the magnesium in different winter rations and for different cows on the same ration. Flaked maize appeared to increase the availability slightly and excessive protein concentrate feeding appeared to depress it.

The following matters were dealt with in the general discussion which followed.

The relative requirements of the sheep and the cow cannot yet be given in all circumstances, but they vary from a total food magnesium of 1 g in the wether to 1·5 g available magnesium for milk alone in the cow. Although actual knowledge based on experiment is lacking, there is no reason to expect that grass which is hypomagnesaemic when grazed would be otherwise when conserved as dried grass. Urinary magnesium could not be employed as an alternative to blood magnesium in day-to-day diagnostic work because *all* urine would have to be collected; results from a portion would not be dependable. No studies had been made to see if a relationship existed between the ruminal production of fatty acids and the availability of feed magnesium. The question was posed whether an excess of water in the gut could depress the absorption of magnesium; the gut required an ionic concentration above a certain level. It was considered unlikely that sufficient Mg^{28} could enter the bones of the mature cow to be of use in studying blood-bone equilibria.

Effects of Fertilizer Treatment of Grassland in Relation to Hypomagnesaemic Tetany

Dr. L. B. O'Moore gave an account of the problem in general and also discussed in detail work done at Johnstown Castle in Eire.[5] He found that the incidence of hypomagnesaemia had tended to increase over the last ten years following grassland improvement. Cases occurred in dairy cattle on spring grazings, in beef cows with calves at foot in cold wet weather, and in ewes about three weeks after lambing. Stresses might be introduced when a beef cow suckled two or more well-grown calves or when a ewe had a cross-bred lamb growing more quickly than one of her own breed.

He considered that there was no correlation between the level of magnesium in herbage and tetany, and said that 0·07 per cent* in the dry matter is generally agreed to be sufficient for a ruminant's needs. Even pure stands of grasses have more than this, and clovers and weeds are richer still. The ratio of potassium to calcium plus magnesium was

* This represents an intake of just under 10 g magnesium if 30 lb dry matter is eaten.

considered important in the Netherlands, high ratios being associated with trouble. Three per cent of potassium had been found in Irish tetanic pastures, but cases had also occurred on potassium-deficient ones.

At the National Institute for Research in Dairying heavy dressings of nitrogen produced a dense, almost cloverless sward and tetany occurred on this, but potash dressings yielded a lighter crop with over 50 per cent of clover and no trouble was experienced on the potash plot. It was also noted that herbage from swards receiving much nitrogen was very rich in crude protein which produced excessive quantities of ruminal ammonia. This ammonia was capable of interfering with the utilization of magnesium. In this connection, it may be noted that Norwegian workers have produced tetany by feeding high-protein low-energy rations which were low in magnesium.

A pilot experiment at Johnstown Castle was carried out on an Italian ryegrass sward. There were six treatments:

(a) no fertilizer; (b) potash only; (c) nitrogen plus magnesium;
(d) nitrogen only; (e) nitrogen plus potash (f) nitrogen plus potash plus magnesium.

When cows were grazed on (a), (b) and (d) there was at first a fall in serum magnesium to about 1·5 mg/100 ml., followed by some recovery in the first two cases, but in no case did symptoms of tetany appear. In (e) there was a progressive fall to as little as 0·5 mg/100 ml and two out of the three cows developed clinical tetany. In (c) and (f) the serum magnesium was fully maintained at about 2·4.* Nitrogen was applied (as 4 cwt calcium ammonium nitrate) at 92 lb N/acre, potassium (as 2 cwt muriate) at 140 lb K/acre, and magnesium (as 5 cwt each of calcined magnesite and magnesium sulphate) at 325 lb Mg/acre.

Suggestions that hypomagnesaemia might be associated with high nitrate or high manganese have not been confirmed. Control of hypomagnesaemia can perhaps be effected by introducing stock very gradually to spring grass, rationing the time of access at first; by grazing leys and old pastures together; by separating the application of the various fertilizers, giving phosphate and potash in the autumn and nitrogen in the spring; and by magnesium compounds applied to the pastures. It was proposed to give advice of this kind on a field scale to Irish farmers. Finally, a very useful diagrammatic summary of the possible interrelated aetiological factors was shown and discussed.

---

* The percentages of crude protein in the dry matter and the K/Mg ratios at the critical times were respectively: (a) 20 and 18, (b) 18 and 19, (c) 25 and 11, (d) 24 and 14, (e) 24 and 22, (f) 24 and 14. Although the ratios in (d) and (f) are identical, the percentage of magnesium in (f) was a third higher than in (d). Figures for $\frac{K}{Mg+Ca}$ cannot be calculated as no analyses for Ca are reported.

The Threshold Value

Discussion on O'Moore's paper was led by *Mr. J. R. Todd* of Stormont, Northern Ireland. He stated that hypomagnesaemia was on the increase in Northern Ireland as elsewhere. He thought that the fact that tetanic and non-tetanic herbages might have similar magnesium contents could distract one from looking carefully for other factors, and he suggested that not only plant-animal, but also soil-plant relationships would be worth studying. In the experiment reported by O'Moore, tetany was experienced on the N+K plot when the Mg was 0·16 per cent, but not when the Mg had been increased to 0·22 by the combined N+K+Mg treatment. He therefore suggested that there is a threshold value above which hypomagnesaemia does not occur; but, at levels below this, hypomagnesaemia (and tetany) may occur through interference by factors such as excessive protein (from high N) and/or excessive potassium. (Dutch workers claim that hypomagnesaemia is to be found when $\frac{K}{Ca+Mg}$ is greater than 2.) The conception of a threshold value could be applied to interpret other experiments.[6,7]

Pot experiments demonstrated that N and P increase the magnesium level in grasses and that K decreases it. Even if all three combined act to increase the magnesium content, the increase may not be sufficient to compensate the adverse influence of high N and K in the herbage.

In the general discussion that followed, it was stated that the distribution of magnesium in soil is either (1) higher in the surface, decreasing with depth, or (2) lower in the surface, increasing with depth. As a rule K and N are higher in the surface. If drainage is impeded, the plant starts off with surface roots, and with soil of the second type insufficient magnesium will be obtained early in the season. As the soil dries out the roots may go deeper and obtain more magnesium as the season advances.

Biochemistry of Hypomagnesaemia

Dr. A. D. Care, Edinburgh, summed up the discussion of these papers in the light of the underlying biochemistry. The fall in serum magnesium in outwintered cattle may be due to a rise in basal metabolism in cold conditions. Inactive hibernating animals have high serum values which fall when activity is resumed. The irritability of the neuromuscular junction is proportional to the Na and K concentrations in the extra-cellular fluid and inversely proportional to Ca, Mg, and pH. Fear and pain increase K (adrenalin increases K) and if the Mg is already marginal the balance may be tipped. This may account for the tetanic convulsions following emotional stresses.

In the Irish experiment it is assumed that all the cows ate the same amount of dry matter, but what if the consumption on the N+K plot were less? It would be useful if the work were repeated in such a way as to allow the determination of magnesium balances. Sometimes, also,

there is a rise in serum potassium when sheep are introduced to spring herbage and this might affect the neuro-muscular junction.

Care[8] also used Mg^{28}, but with a different technique from that of Field, and obtained very similar results on hay. Calculations showed that two-thirds of the extra-cellular magnesium was excreted daily in the faeces. If, therefore, there is no control over endogenous faecal excretion, a sudden reduction in absorption might deplete the extra-cellular fluid. There is the possibility that, rather than a decreased absorption occurring on lush pasture, there may in fact be an increased endogenous faecal excretion. Transfer to such pastures has caused an increase in volatile fatty acids in the blood and a drop in blood pH. This is followed by a fall in serum magnesium. The problem requires a study of endogenous metabolism on stall feeds and again on pastures.

Experimental Results from N.A.A.S. Regions

These were presented by *Dr. Rice Williams* of Aberystwyth. Many of the studies were still in progress and it was not possible to report on these, but some had reached completion or had been continued for a sufficient number of years for a pattern to emerge.

The general finding was that a seasonal variation occurs in the magnesium content of herbage, the lowest figures usually being in the earliest cuts. In Wales, a single application of 2 tons/acre of magnesian limestone was made in January 1957, and the effect was followed thereafter by cuts taken every three weeks during the growing seasons. The percentage increases, based upon the means of all cuts in any one year, were 16, 30, and 37 for 1957, 1958, and 1959 respectively. The initial pH of the soil was 5·5.

A similar trial in Warwickshire[9] gave increases of 23, 79, and 80, the initial pH being 5·2. In Hampshire on a soil with a pH of 6·0, increases in the first 2 years were 20 and 34 per cent. As might be expected, less response was obtained on alkaline soils. At pH 7·1, the responses were 6, 8 and 12 over 3 years; and at another site with a pH of 7·7 they were 0, 5, and 9.

Trials with Epsom salts ($MgSO_4.7H_2O$) at 10 cwt/acre showed that it was much less effective. This quantity, of course, provided only one quarter of the magnesium present in 2 tons of magnesian limestone, both materials having approximately 10 per cent of magnesium. The effect in the first year was to produce an increase of between 10 and 20 per cent, but in the second year this fell away to below 5 per cent. At Cardiff, Epsom salts were applied at the rate of (a) 5 cwt in the first year only, (b) 5 cwt in each of the first two years, and (c) 5 cwt in each of the three years. The means of the first 4 cuts in each of the 3 years (i.e., the means of 12 in all) were (a) 7 per cent, (b) 14 per cent, and (c) 17 per cent above the controls. Such results do not encourage the use of a rather costly chemical.

Calcined magnesite at 5 cwt/acre (equivalent to 2·64 cwt magnesium) produced increases of 114 and 73 per cent above the control in the year

of application and in the year following in the Warwickshire experiment already mentioned. It will be seen that this material provides a quick improvement, but that the dolomitic limestone at 2 tons/acre (equivalent to 3·43 cwt magnesium) catches up after a year or so.

Work at Trawscoed in 1959 on red and white clovers, on cocksfoot and on Italian ryegrass, showed a rapid climb in the magnesium content of the clovers as the season advanced, red being superior to white, and both clovers exceeding the grasses. The cocksfoot was slightly superior to the ryegrass, which, in this season, showed a minimum in mid-June.

Trawscoed had studied the easily soluble soil magnesium under different treatments. That of the control and ordinary limestone plots remained throughout at 4 to 5 mg/100 g soil. With one application of 5 cwt Epsom salts, the soluble soil magnesium was 10 mg after 10 months and 7 mg after 2 years. With one application of 2 tons magnesian limestone, the corresponding figures were 15 and 27 mg.

General Discussion

This was opened by *Dr. Ruth Allcroft* who spoke on the work done at Weybridge. Administration of supplementary magnesium was a problem only with animals getting nothing but grass. Spraying or dusting magnesium compounds on herbage for direct consumption by the animal would require uneconomic repetition. Attention was therefore directed to achieving internal improvement of herbage by application of fertilizers.

As calcined magnesite is costly, work was now being done to test the effectiveness of dressings smaller than those originally used. From 1955, four treatments had been applied at a site: (P) triple superphosphate each year; (PN) superphosphate plus 6 cwt sulphate of ammonia each year; (PNML) 50 cwt magnesian limestone the first year, and supers plus S/A every year; (PNCM) 10 cwt calcined magnesite the first year, and supers plus S/A every year.

PNCM produced a 70 per cent and PNML a 20 per cent increase in magnesium content over the control. Further, although there was a seasonal trend, maximal values occurred in PNCM at the time when grass growth was most rapid in spring and autumn, and no hypomagnesaemia had occurred in the five grazing seasons since the commencement. Mild hypomagnesaemia occurred on PNML in the 4th and 5th seasons. Hypomagnesaemia, either clinical or sub-clinical, occurred on the other two plots. (Some of this work is reported under reference 7.)

The effect of a heavy potash dressing as well as nitrogen had the effect of causing clinical hypomagnesaemia, confirming Dutch and Irish observations.

Further trials with quantities of calcined magnesite ranging from 1 to 10 cwt/acre showed that, on a moderately acid soil, 2 to 4 cwt increase herbage magnesium sufficiently to control hypomagnesaemia. Heavier applications are necessary on soils with little or no lime

requirement. No harm was done to herbage by quantities up to 10 cwt/acre.

Applications through the soil are not likely to solve the problem for outwintered beef cattle, as there is little growth of grass at the time when their serum magnesium levels are lowest.

There was an active wide-ranging discussion on all the papers presented. One speaker claimed that 2 or 3 cwt of calcined magnesite had increased herbage magnesium by one-third in one year, whereas dolomite had no effect even on acid soil. This was countered by findings at the Macaulay Institute that although dolomite may be slow at first, a 50 per cent increase in magnesium can occur over 3 years. The ratio of Ca to Mg decreased from $\frac{30}{1}$ to $\frac{5}{1}$ in the soil, but after a time the effect was reversed. Plots which received dolomite in 1944 had shown an increase of easily soluble magnesium from 4 up to 50 mg/100 g soil, but the figure was now back at 4. During this time plants had removed four times as much magnesium from the treated as from the untreated plots.

The suggestion was made that unless the plant required magnesium on its own account it was more important to consider ways of direct feeding to the animal. A palatable mixture could be made up (cubed if necessary) for little more than the price of a cereal meal and which would carry 2 oz calcined magnesite per lb. A month's feeding, 30 lb per cow, would cost about 7*s*.

There was some discussion on the correct amount of calcined magnesite to be fed. Dr. Allcroft thought that 2 oz was adequate, although 1 oz might be borderline, but Dr. Rook thought that heavy milkers in spring would need more than 2 oz, although beef cattle would not need as much. Free grazing was necessary to collect all the dry matter necessary (which might or might not have sufficient magnesium) and free-grazing cows might refuse concentrates. Work on other magnesium compounds was needed to determine the best type for supplementation.

Hypomagnesaemia in dairy cattle has been controlled at the Hannah Dairy Research Institute by feeding to each cow daily 1 lb of concentrates containing 1 oz calcined magnesite for 5 weeks in April and May. Fertilizer policy had been altered at the same time, and although the average annual application of nitrogen is maintained at 100 lb per acre, potash has been reduced from 120 lb or more to 60 lb or less and no fertilizers containing potash are applied in spring or early summer. Further, half of the total acreage of the farm has been given 2 tons per acre of magnesian limestone.

On soil-plant relationships, the remark was made that information is not always given as to the form in which N is applied—as NH_4 or as NO_3—and the form may influence the uptake of magnesium. The view was expressed that a magnesium deficiency had developed in many soils because of intensive production in recent years and of the use of modern fertilizers which contain little or no magnesium

naturally. To remedy this, a deliberate policy of magnesium manuring would be necessary. While not disagreeing with this, another speaker thought that it would be sufficient to supply only as much magnesium as would be required to maintain a suitable level in herbage during the years when a ley was being grazed. This would provide an ample carry-over for crops following ploughing-up and until the land was again sown down to grass.

The symposium may not have solved any outstanding problems, but it was extremely valuable in bringing together the present sum of knowledge and showing in what direction further effort was required. In the opinion of those attending, the exercise was very worthwhile.

References

1. Field, A. C., McCallum, Jennie W., and Butler, E. J. *Brit. J. Nutr.*, 1958 **12,** 433–46.
2. Field, A. C. *Nature*, Lond., 1959, **183,** 983.
3. Rook, J. A. F., Balch, C. C., and Line, C. *J. agric. Sci.*, 1958, **51,** 189–98.
4. Rook, J. A. F., and Balch, C. C. *J. agric. Sci.*, 1958, **51,** 199–207.
5. Smyth, P. J., Conway, A., and Walsh, M. J. *Vet. Rec.*, 1958, **70,** 846–9.
6. Bartlett, S., Brown, B. B., Foot, A. S., Rowland, S. J., Allcroft, R., and Parr, W. H. *Brit. Vet. J.*, 1954, **110**, 3–19.
7. Parr, W. H., and Allcroft, Ruth *Vet. Rec.*, 1957, **69,** 1041–7.
8. Macdonald, D. C., Care, A. D., and Nolan, B. *Nature*, Lond., 1959, **184,** 736–7.
9. Griffiths, T. W. *J. Brit. Grassl. Soc.*, 1959, **14,** 199–205.

Regional Note

Studies of the Chemical Composition of Forage Crops in Wales

D. J. C. JONES

*National Agricultural Advisory Service, Wye, Kent**

THE ACREAGE of forage crops grown in Wales for winter feeding has risen during the last twenty years from 15,000 to 77,000 acres. These crops are almost entirely kale and rape, but the cattle cabbage is still grown on a limited scale.

Kale and rape are firmly established as feeds for dairy cows during the early winter period. In areas where the climate is suitable, a succession of kale can be used to provide grazing throughout the winter period. As well as being popular with dairy farmers, rape is still very widely used in the traditional manner for fattening lambs.

Using forage crops on this large scale has raised many advisory problems concerning nutritional composition, and the way it is affected by such factors as type of crop, degree of utilization, stage of maturity, and plant population per acre. Little work had been done previously which could be used to answer such questions, and practically all the information available referred only to kale. For this reason the investigations reviewed in this article were carried out in the Nutrition Chemistry Department at Trawscoed, to provide information on the composition of the forage crops which could be used for the assessment of their probable feeding values.

Kale

Agriculturally, the most important groups of kales are the marrowstem and thousandhead. Several trials have been conducted to find out the differences in composition between these groups and the main types within them. The most important factor influencing composition has been found to be the leaf-to-stem ratio of the crop, since the leaves and stems differ markedly in composition. On a dry matter basis, this ratio is generally between 0·4 to 0·7 in the marrowstem kales and 1·5 to 2·0 in the thousandhead kales. Typical analyses for marrowstem and thousandhead kales are given in Table 1 overleaf, and the importance of the leaf-to-stem ratio can be seen. On a dry matter basis, the leaves in both groups are much richer in crude protein and calcium than the stems, and lower in crude fibre and nitrogen-free extractives.

* Formerly stationed in Wales.

Table 1

Typical Analyses found for the Main Forage Crops

Forage Crop	Part of Plant	Dry Matter *per cent*	Percentage Composition of the Dry Matter					
			Crude Protein	Crude Fibre	Nitrogen-free Extractives	Calcium	Phos-phorus	Mag-nesium
Marrowstem Kale .	Leaf	14·42	23·21	10·45	49·26	2·05	0·38	0·22
	Stem	11·39	13·30	19·69	56·27	0·66	0·35	0·19
	Whole plant	12·31	16·87	16·38	53·72	1·16	0·36	0·20
Thousandhead Kale .	Leaf	15·16	19·83	11·32	52·81	1·59	0·41	0·20
	Stem	20·05	11·89	25·79	54·29	0·47	0·38	0·19
	Whole plant	16·69	16·88	16·72	53·35	1·16	0·40	0·19
Giant Rape . .	Leaf	16·48	25·98	10·51	47·46	1·54	0·48	0·24
	Stem	21·68	15·79	21·78	54·16	0·54	0·35	0·19
	Whole plant	17·86	22·30	14·54	49·74	1·22	0·43	0·22
Broad-leaved Essex Rape	Leaf	15·83	22·96	11·28	50·74	0·81	0·44	0·20
	Stem	22·46	13·12	20·61	58·13	0·34	0·32	0·17
	Whole plant	17·91	18·98	15·06	53·68	0·63	0·39	0·19
Rape-type Kale . .	Leaf	15·00	25·76	10·09	48·67	1·34	0·47	0·22
	Stem	19·99	18·46	16·06	56·96	0·52	0·41	0·19
	Whole plant	16·37	23·29	12·12	51·47	1·06	0·45	0·21
Cattle Cabbage . .	Whole plant	10·40	18·22	12·11	54·63	2·25	0·25	0·13

It is not possible, however, to make comparisons between marrowstem and thousandhead kales solely on the basis of leaf-to-stem ratios. If these ratios are expressed on a green basis, they do not allow for the considerable difference between the dry matter levels of the stems in the two groups. In the thousandhead group, the dry matter in the stem is much higher than in the leaves, whereas it is the opposite for the marrowstem group. The leaf-to-stem ratio can be expressed on a dry matter basis to avoid this discrepancy. However, the harder stems of the thousandhead kales are lower in crude protein and calcium and higher in crude fibre than the fleshy stems of the marrowstem varieties. Thus, although marrowstem kale is inferior through having lower leaf-to-stem ratios, it is superior because its stem is of higher feeding value. Consequently, on a whole plant basis, there is very little difference between the composition of these two main groups of varieties.

Variation in Composition

No differences in composition have been found between the various types of thousandhead kales except those due to varying leaf-to-stem ratios. In the marrowstem group, however, there is a much wider range of stem composition due to the relative fleshiness of the stems. An illustration of this variation is seen in the case of the Purple Stem Kale, which, although classed as a marrowstem kale, resembles the thousandhead types in having a higher leaf-to-stem ratio and a less fleshy stem. This stem resembles the thousandhead kales in having a higher dry matter content, but its composition on a dry matter basis is similar to that of the other marrowstem kales.

When kales are grazed, they are only very rarely completely utilized. This means that the composition of the material consumed by the animal may differ considerably from that of the whole plant. The leaf and the top third of the stem are almost invariably eaten, but the remainder of the stem is rejected to varying degrees. For this reason, the distribution of the major nutrients has been investigated in the various horizons of the stem, and Table 2 gives typical analyses of these parts of the stems of marrowstem and thousandhead kales. As might be expected, the dry matter of the lower levels of the stems is a much poorer source of crude protein and to a lesser extent calcium and phosphorus; in addition, it is much higher in crude fibre. When utilization is incomplete, therefore, the least nutritious portions of the plants are rejected.

It is of interest to note that the rejected portions of the crop are also highest in dry matter. With the marrowstem kale crop, for which analyses are given in Table 2, the lowest third of the stem, which would almost certainly be unconsumed, contains 41 per cent of the dry matter in the stem and 27 per cent of the dry matter in the whole plant. Therefore yields which are quoted for the crops without due regard to the probable degree of utilization give an exaggerated impression of the amount of nutrients which they supply.

Preliminary work showed that as kale matured there were slight increases in the dry matter of the crop with an increase in the crude protein levels in the dry matter. Detailed trials subsequently carried out both with marrowstem and thousandhead kales have shown that such increases are not of very great significance. There were no changes in either the crude fibre, calcium or phosphorus levels in the dry matter of these types as the season advanced.

Table 2

	Marrowstem Kale			Thousandhead Kale	
	Top Stem	Middle Stem	Bottom Stem	Top Stem	Bottom Stem
Dry matter percentage	9·01	11·20	16·63	14·90	19·30
	Percentage composition of the dry matter				
Crude protein	14·88	8·58	6·13	18·11	11·64
Crude fibre	15·32	23·74	35·62	22·87	42·92
Nitrogen-free extractives	57·00	55·93	47·74	48·79	39·63
Calcium	1·00	0·80	0·75	0·85	0·68
Phosphorus	0·33	0·22	0·15	0·37	0·29
Magnesium	0·14	0·13	0·13	0·14	0·12

Kale crops, particularly of the thousandhead varieties, are now frequently grown unsingled in the rows or broadcast. This has the effect of producing plants having low leaf-to-stem ratios with a consequent effect on their composition when expressed on a whole plant basis. The effects of singling on the composition of the various parts of the plant have been investigated using thousandhead kales grown at the rates of approximately 45,000 and 11,000 plants per acre. As might be expected, the differences found in composition are in the stems. The stems of the singled crops are lower in crude fibre and to a much lesser extent, calcium, but higher in phosphorus. They are also slightly higher in crude protein, but this increase is in the lower portion of the stem which would not normally be eaten.

The composition found for the kales in all the trials reviewed here is in fairly good agreement with that reported previously by British workers and it suggests that the crops have a feeding value which is not substantially different from that given in "Rations for Livestock". This feeding value is unlikely to be affected significantly by variety, stage of maturity or plant population per acre. It is affected considerably, however, by the degree of utilization of the crop as a result of the different composition of the various parts of the plant.

Rape

Rape is normally considered in three main groups: giant rape, broad-leaved Essex rape, and rape-type kale. The last group consists of the Hungry Gap Kale and Rape-Kale, which, despite their names, are true rapes.

Differences between these groups lie mainly in their height of growth and size of leaf. It might be expected, therefore, that their composition and relative feeding values will depend, as with kale, on their leaf-to-stem ratios. A very wide range of ratios has been found from 0·8 to 2·4 on a dry matter basis, but no consistent differences have occurred between the groups. There have been no consistently significant differences in the chemical compositions of the groups which are given in Table 1. As was found with kale, the dry matter of the leaves of rape is much richer in crude protein and calcium than the stems and also lower in crude fibre and nitrogen-free extractives. A leafy crop, therefore, will be superior to a stemmy one as a source of protein and minerals. However, it will not supply the same level of carbohydrates and this could be of significance when stock such as fattening lambs are consuming it as the sole article of diet.

The composition of rape leaves in the early winter has been found to resemble that of kale leaves, whilst rape stems are similar in composition to those of thousandhead kale. It is probable, therefore, that there is no great difference in the relative feeding values of the crops as grown and used in Wales. This finding supports the conclusion made by workers in New Zealand that rapes have a higher starch equivalent than that quoted in Bulletin No. 48, "Rations for Livestock."

On dairy farms, rape is normally grazed off early in the winter before kale. In some instances, however, rape is grazed much later in the season. A limited investigation into the effects of advancing maturity on the composition of the crop has shown that a considerable increase in crude protein occurs in the dry matter of both the leaves and stems.

Table 3
Crude Protein in Rape
(expressed as percentage of dry matter)

	Cut 2nd December			Cut 30th January			Cut 11th March		
	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant	Leaf	Stem	Whole Plant
Hungry Gap Kale	25·72	19·60	23·60	33·60	19·69	25·70	36·22	21·35	35·60
Giant Rape	24·15	15·70	20·52	31·14	16·80	24·38	29·12	16·10	21·59

This is illustrated in Table 3 above, which indicates the very high levels

which can be reached. When expressed on a whole plant basis, the increases are not as marked because the increases of crude protein in the leaves and stems are offset by the reduction in the leaf-to-stem ratio of the crop due to leaf fall. Rape grazed later in the winter must be considered, therefore, as being a richer source of crude protein than kale, but lower in carbohydrates.

Cattle Cabbage

Cattle cabbage is grown on a limited scale as an alternative to kale, particularly where the crop cannot be grazed and has to be cut and carted. The composition found for the crop, and shown in Table 1, compares fairly closely with that found for marrowstem kales grown under similar conditions. There are differences, however, which are of importance in assessing the relative feeding values of the crops. Cattle cabbage contains approximately 2·5 per cent less dry matter than marrowstem kale and, on a dry matter basis, it has a lower crude fibre content, which is comparable with that of kale leaves. Crude protein values for the two crops are comparable. In practice, strip-grazed kale might be a superior source of crude protein, due to rejection by the stock of the portions of kale lowest in crude protein. Cattle cabbage is also a good source of minerals, except possibly magnesium, and it should be considered as a dietary replacement for kale and not roots as has sometimes been suggested.

The composition of cattle cabbage is not influenced in the same way as kale by its leaf-to-stem ratio, since the stem makes up only a small proportion of the plant. There are marked differences, however, between the composition of the outer leaves, the inner leaves, and the stem of the crop as shown in Table 4. This leads to differences in the compositions of the open-leaved and drum-head types of cattle cabbages. Thus, the drum-head types, with a high proportion of heart leaves, are lower in dry matter than the open-leaved types. The dry matter of the drumheads, however, is higher in crude protein and lower in crude fibre and calcium.

Table 4

Composition of Fractions of Cattle Cabbage

	Outer Leaves	Inner Leaves	Stems
Dry matter percentage	10·04	7·94	10·47
	Percentage of the dry matter		
Crude protein	19·80	24·02	17·94
Crude fibre	15·17	12·14	17·89
Nitrogen-free extractives	49·79	53·86	55·85
Calcium	2·12	1·13	0·71
Phosphorus	0·29	0·32	0·38
Magnesium	0·14	0·13	0·13

As the winter progresses, cattle cabbage lose their outer leaves as a result of frost damage. The effects of this damage and advancing maturity on the composition of the crop have been investigated and found to be relatively small. The only changes of any significance are an increase in the crude fibre levels in the dry matter with a corresponding decrease in the levels of the nitrogen-free extractives.

Minerals

The three main forage crops discussed have been found to be good sources of calcium and phosphorus. The balance between the two elements is satisfactory where the crops have been grown on soils which are slightly acid but, where there has been a liberal supply of lime, calcium values have been excessively high. The concentration of calcium in the leaves of kale and rape, particularly of marrowstem kale, can lead to an unbalance of the elements in the material grazed by stock. This is particularly so when the degree of utilization is very low, and the problem can be of considerable significance when forage crops make up the bulk of the animal's diet.

Magnesium values in kale, rape, and cabbage have been found to be low in all but one trial. It appears, therefore, that under the conditions of soil and climate in mid-Wales the crops are a poor source of the element. However, further work is necessary to investigate the extent to which this observation may have general application.

The levels of the agriculturally important minor elements have been investigated in kale and rape. The most significant results of this work have been the low levels of copper and manganese found in forage crops when grown on soils which were not conducive to such low levels in other crops. The precise significance of these low levels of manganese in the nutrition of stock is not clear. It appears quite possible, however, that a simple deficiency of copper could occur in diets made up largely of forage crops. The levels of molybdenum, which, if they were high would exert a limiting effect on copper absorption by stock, have always been found to be low. The sulphate ion, however, which when present in excess of a critical level has been shown to permit molybdenum to exert its full limiting effect on copper absorption, has been found to be present in excess of this level in all the investigations carried out with the three forage crops. They have also been found to be very rich sources of sulphur combined in other forms.

Rape is often grown as a pioneer crop during the reclamation of marginal land and it is subsequently grazed off by fattening lambs. It is important, therefore, that the crop supplies adequate cobalt to prevent unthriftiness in the lambs. Limited investigations have shown that cobalt, unlike copper, is present in both rape and kale in amounts adequate to meet the requirements of stock grazing them.

The production of milk from kale has often been found to be below that which might have been expected, particularly in wet seasons. It has been suggested that this might be due to the crop supplying

insufficient iodine. Preliminary results suggest that kales, particularly the marrowstem varieties, are poorer sources of the element than mixed grass and clover swards. This work, however, must be repeated on a much larger scale before general conclusions can be drawn.

Other Forage Crops

Forage crops have now become an integral part of winter feeding and considerable work is being done by research stations to develop more suitable types of the established crops and to introduce new ones. Several of the newer introductions have been analysed and their composition compared with that of the established crops. The purple-sprouting broccoli, curly kale and cottagers kale have been found to have compositions similar to that of thousandhead kale, while fodder spinach and fodder radish have a composition similar to that of rape. The fodder radish also produces a root which has roughly the same composition as that of the turnip.

Information which was lacking on the composition of forage crops used in winter feeding has been provided by the work reviewed in this article. This information is helpful in assessing the probable feeding values of the crops, but it is an inadequate substitute for assessments made on the basis of feeding trials with animals. Such trials are essential for the full understanding of the factors influencing the nutritive value of this increasingly important group of feeds.

S.O. Code No. 72-20-60-3